Analysis of human eye movements during the plot inspection as a tool of assessment of local informative value of the 12-lead ECG

Ryszard Tadeusiewicz, Piotr Augustyniak
AGH University of Science and Technology, Krakow

Abstract: The main goal of every method of automatic analysis, recognition and also understanding of any medical signal is to follow the physician's method of observation and thinking. Apparently it is easy, because the procedures of human interpretation of biosignals are now well standardized. In fact the real way of making observations and thinking about diagnosis highly depends on the observer experience and personal skills. In this paper, a new eyetrack-based approach is proposed for quantitative assessment of these important factors. The visual experiment carried out on cardiologists of various professional experience supplied the scanpaths data for the analysis in context of observed ECG traces The proposed approach, without the verbalization necessity, allows the cardiologists know-how to be extracted, analyzed and implemented in the automatic interpretation algorithm for better emulate the human way of thinking. In can be very useful for designing of new algorithms for automatic ECG signal analysis, recognition and also understanding by the machines.

Keywords: eyetracking, visual search, electrocardiogram, human perception

1. INTRODUCTION

One of the intrinsic features of biosignals is the irregular temporal distribution of diagnostically important components. The general variability rules relating the medical content of the signal and its expected statistical parameters (e.g. instantaneous bandwidth and reliability) are very interesting in aspect of adaptive biosignals and data transmission in distributed interpretive monitoring networks. Unfortunately, studies providing quantitative, signal content-related description of irregularities are rarely reported in literature.

Our work aims at the investigation of the signal informative content beyond its technical parameters and assumes the use of medical knowledge. This implies the co-operation of experienced people and makes the results very sensitive to human factors: prejudging, verbalization and others. Continuing our research on local vulnerability of the ECG record to the distortion [1], in this paper we investigate the local variations of the ECG trace conspicuity.

Perceptual models have been recently recognized as valuable tool enriching the visual interaction of human with sophisticated devices [2] [3]. As a *perceptual model* of a biosignal record we understand a result of statistical processing of scanpaths, analyzed as polygonal curves in context of background visual information. The gaze order and fixation time correspond to the seeking sequence and to the amount of data gathered visually by the observer and thus represent the diagnostic importance of particular regions in the scene [4][5]. In the ECG, subsequent events in the cardiac cycle are represented by waves positions, therefore the wave start- and endpoints were selected as reference time points for the analysis of human foveation sequence aiming at estimating the local density of medical data. Assuming the observer is properly engaged in the

trace inspection, the gaze is controlled instinctively and the eyeglobe movements objectively represent the information gathering sequence. The analysis of experts' eyeglobe trajectories captured during the manual interpretation not only reveals regions of particular importance in the signal trace, but also represents the human reasoning involved in the interpretation process [6].
Apart from main interest of our research, the prospective area of applications for eyetrack features captured during the visual inspection of biosignals include:

- objective assessment of cardiologist interpretation skills,
- prediction of required transmission channel parameters from the automatic rough estimation of medical contents,
- teaching of the visual interpretation using the guided repetition of expert's scanpath,
- application of human reasoning and non-verbalized rules in machine interpretation algorithms.

2. MATERIAL AND METHODS

This chapter presents the eyetracking equipment, visual tasks methodology and the visual experiment carried out with an aim to reveal the local ECG informative value.

2.1 Eye tracking method

The infrared reflection-based eyetracker OBER-2 [7] capturing two-dimensional trace of each eye at 750 Hz during the ECG presentation lasting for 8s was used in visual experiments. The device provides the angular resolution of 0.02 deg and uses time-differential method for the sidelight discrimination. This angle represents a time interval of 30 ms on a standard ECG chart plot (25mm/s) viewed from a typical reading distance (40 cm). The position of both eyes was recorded simultaneously and a custom-developed software detects the dominant eye which trace is used to determine the electrocardiogram conspicuity. Figure 1 displays the physical background of the differential infrared reflection-based eyetrack acquisition.

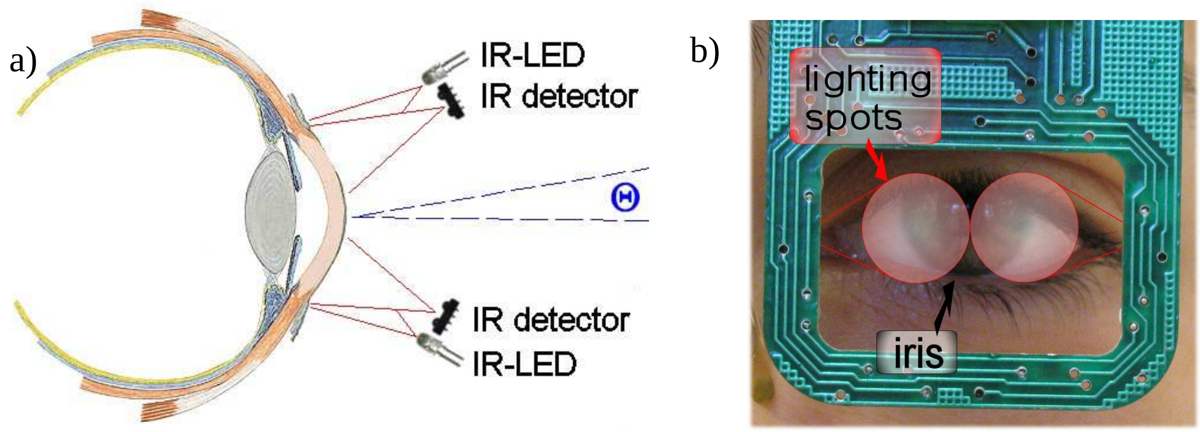

Fig. 1. a) Physical principle and b) technical details of the infrared reflection-based eyetracker OBER-2

2.2 Observers Population

The total of 17 experts (12 ± 4 years of experience) volunteers were invited to the laboratory for the visual experiment. All observers were asked to complete the statistical questionnaire on their ECG experience and possible eyesight defects before attempting to the visual task. Unfortunately, the optical glasses were very frequent in the experts group and particular conditions had to be observed in order to avoid side effects to the scanpaths. The glasses artifact is reduced if the relative position of glasses and eyetracker goggles remain unchanged during the calibration and the measurement phase.

2.3 Reference Traces

The ECG traces were randomly selected for interpretation from CSE recordings [8] and were presented as bitmaps on a 17 inch CRT monitor. The display simulated a conventional 12-leads paper recording (fig 2). The reading distance was controlled with use of a chin support set in a distance of 40 cm distance from the display center. Each ECG trace presentation was interlaced with the fixation point in the center of the display.

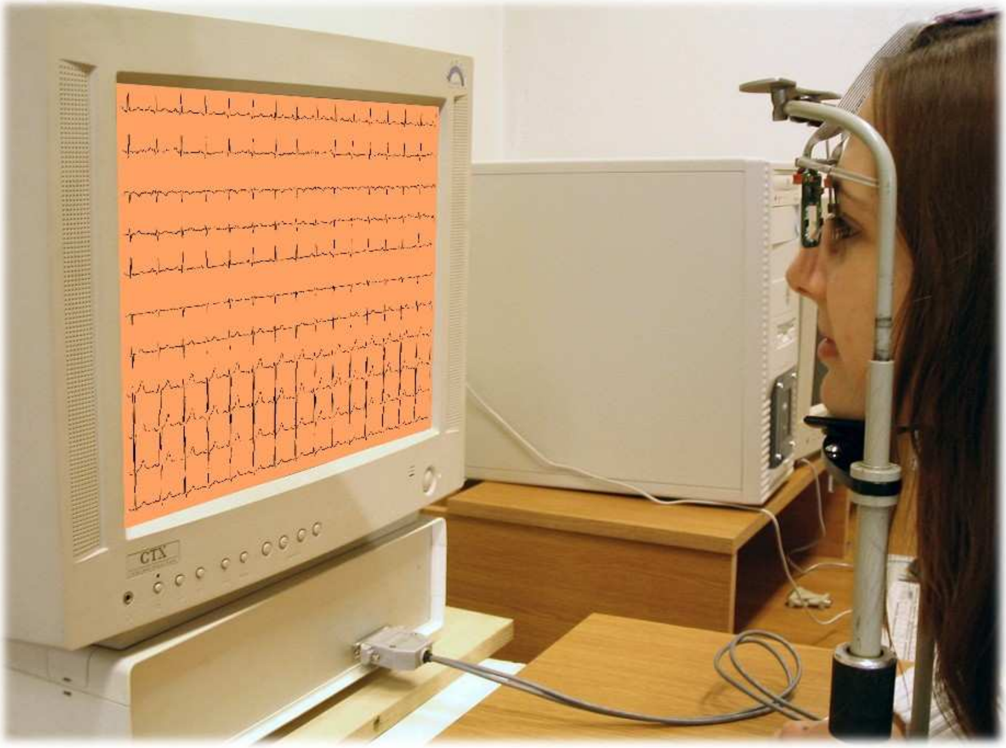

Fig. 2. The expert volunteer performing a visual task on ECG interpretation

Each observer was asked for the interpretation of 8 traces. Each of 123 database traces appeared 2 to 4 times (2.43 on average). Pacemaker-stimulated recordings no. 67 and no. 70, were excluded for the lack of waveform reference points in the database. The reference wave borders, although not displayed, provided the cardio-physiological context for the scanpaths analysis. The horizontal axe of the scanpath is projected on the heart cycle temporal progress, represented by waves border positions, in order to estimate for each cardiac component the amount of information it contributes to the final diagnosis.

2.4 Scanpaths Signal Processing

Each visual experiment provides a four-column matrix representing raw eyeglobe coordinates at the evenly spaced time points [9]. Prior to the ECG traces investigation the calibration rectangle is displayed and the observer is asked to gaze at its corners. The gaze points corresponding to the corners are identified in the eyetrack and help in calculating the display-relative coordinates from the A/D converter output.

The further signal processing routines were developed in Matlab with regard to the aims of visual experiments. Main stages of this calculation are performed on the pre-detected dominant eye trace and include:

- the initial idle time and the interpretation task completion time were detected in the scanpath,
- using a set of reference wave borders provided in the CSE database, each foveation point in the scanpath was qualified as belonging to the particular ECG section,
- the number and duration of foveation points was averaged separately for each ECG section in all ECG displays,
- the contribution of each section's conspicuity was referred to the total observation time.

The intrinsic variability of waves' length does not influence the result, since the foveation points are referred to ECG fiducial points and not directly to the ECG time

Apart of the waves conspicuity statistics, the processing reveals the perceptual strategy related to main stages of the ECG interpretation process. The principle of strategy description is the identification of (1) most attractive points coordinates and (2) their gaze order in context of the ECG time and displayed ECG leads. These parameters were chosen as most representative to the global density of diagnostic information distribution in the heart cycle and to the information priority required by a diagnostic decision scheme followed intuitively during the manual ECG interpretation by the human expert.

3. RESULTS

The statistical parameters of all visual experiment results are summarized in table 1. Figure 3 displays an example of eyeglobe trajectory over a 12-lead ECG plot together with the corresponding bar graph of attention density.

Table 1. Results of ECG inspection scanpaths analysis

Parameter	Unit	Observers Experts
idle time	ms	73 ± 55
interpretation time	s	5.5 ± 1.5
P wave foveation	%	23 ± 12
PQ section foveation	%	7 ± 5
QRS wave foveation	%	38 ± 15
T wave foveation	%	18 ± 10
TP section foveation	%	14 ± 5
max. attention density	s/s	21.0
min. attention density	s/s	1.9

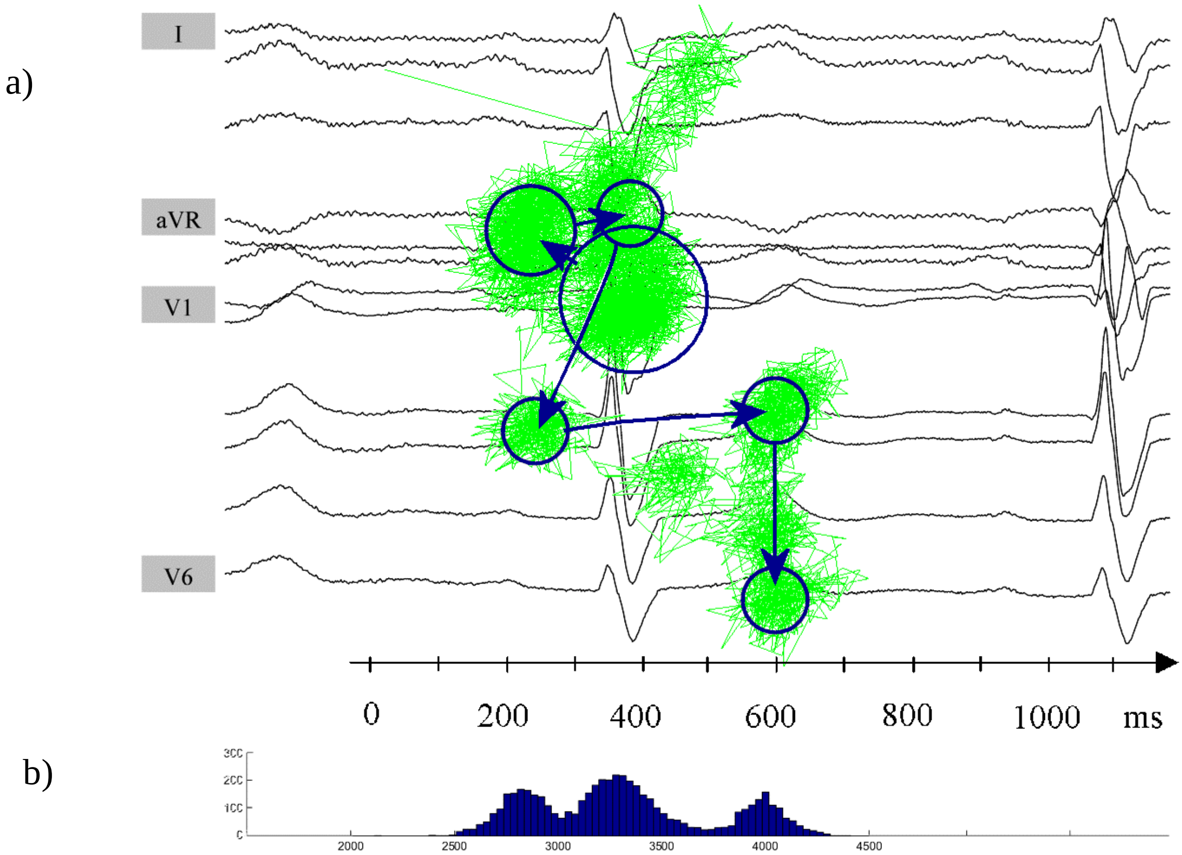

Fig. 3 a) The example of expert's eyeglobe trajectory over a 12-lead ECG plot (CSE-Mo-001) ; the circle diameter represents foveation time, b) corresponding bar graph of the attention density

The results in table 1 prove the common belief about irregular distribution of medical data in the electrocardiogram. However, main novelty here is the quantitative assessment of expert's attention density and its variations in the heart cycle. As much as 38 percent of information in the signal is represented in the QRS complex attracting the experts' gaze to this relatively short (105±23 ms) section. Despite the considerable length of the baseline (278±115 ms), only 14 percent of gaze points fall to the this section confirming its little diagnostic significance. Comparing minimum and maximum attention density values we found interesting that this value varies over 10 times, what represent high expert concentration on most informative part of the image. This value should also be interesting for estimation of the efficiency of ECG-dedicated perceptual compression method.

The second group of result were derived by the analysis of perceptual strategy. Figure 3a displays an example of the strategy over a 12-lead ECG plot and table 2 summarizes the corresponding strategy description parameters.

For the studies on perceptual strategy repeatability we selected electrocardiogram images investigated by at least two observers. By comparing the positions and gaze order of five most important foveation points in the scanpaths we found several different strategies applied by the experts. Having no means to assess them, we only rank them by frequency and state, that the similarity between two experts may be expected with the probability of 37%. This result prove the proper representation of ECG interpretation process in the visual strategy.

Table 2. Quantitative description of the most frequent perceptual strategy

Parameter	Unit	Observers Experts
relative foveation time for the main focus point	%	31 ± 12
number of foveation points[1]		6.1 ± 1.7
foveation points distance	deg.	5.7 ± 2.4
scanpath length to the last foveation point[2]	deg.	34.7 ± 5.1
scanpath duration to the last foveation point[2]	s	3.6 ± 1.3

The eye tracks gathered during the visual experiments need further exploration and contextual analysis with regard of CSE database records and the medical significance of the data. The example of unexplored area is the correctness of medical diagnoses made on a background of visually inspected traces.

4. DISCUSSION

Visual experiments provide a quantitative description of the trace conspicuity in context of cardiac events represented in the signal. The scanpath advantages place it among most useful tools for investigation of human mental processes, surrounding perception and interaction as well as man-machine interfacing.

The scanpath, however, is very sensitive to the voluntary observer cooperation during visual tasks. Poor co-operation or misunderstanding of visual task rules was the main reason for exclusion of 18% of records from the scanpaths statistics. The result is also influenced by psycho-physiological factors difficult to control during the visual experiment:

- observer-dependent features varying from one person to another: eyesight defects influence, anatomy, perceptual and motoric skills, sex, race etc.
- observer status-dependent varying for each person from one day to another: psychophysiological status, drugs, climate influence etc.

The identification of basic phenomena interfering the relation of scanpaths and visual perception information flow took three years, and needed the analysis of various visual experiments results. Another challenge was the development of scanpaths pre-processing software towards standardizing and minimum operator assistance in recognition of desired trace features.

[1] having at least 5% of relative foveation time
[2] to the last point having at least 5% of relative foveation time

The scanpath statistics and perceptual strategies revealed many differences between cardiology experts concerning the ECG inspection methods. However, all the statistical parameters indicate a very precise and consistent way of information search by experts. Moreover, high variation of first foveation points focus time and distance suggest the hierarchical information gathering reflecting the parallel decisive process.
In the future, these research would be continued towards:

- extraction of heart disease-typical perceptual strategy, optimization and implementation in machine-interpretation algorithms;
- proposition of perception-based teaching and learning progress assessment rules;
- objective assessment of cardiologist interpretation skills,
- pursuit for the interpretation-related mental processes, which can not be controlled and reported knowingly without affecting the perception process.

5. CONCLUSION

The reported research demonstrates that the common belief on irregular medical data distribution is fully justified for the electrocardiogram. With the use of scanpaths analysis, the local data distribution can be effectively measured and expressed as attention density.

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